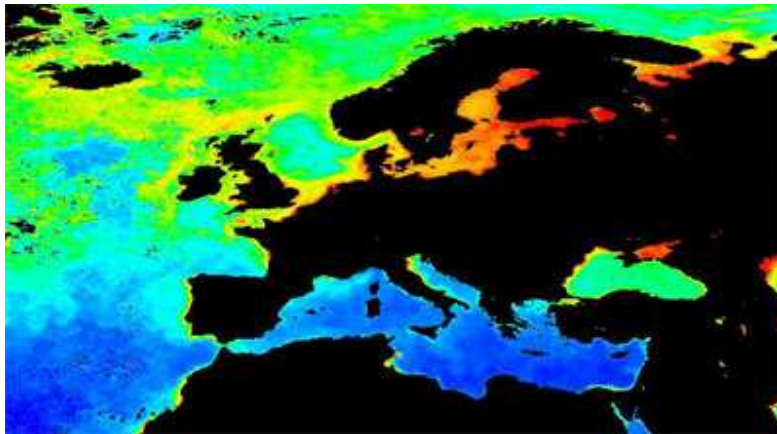




# **Nutrient dynamics in European water systems**

**(Three show cases for an internet application)**



**CONCEPT 09-06-2004**



**Netherlands Institute of Ecology (NIOO-KNAW)**

**Centre for Estuarine and Marine Ecology, Yerseke (NL)**

## Foreword

*'In the face of growing concern over eutrophication problems in freshwater systems, P levels in European and North American rivers have been reduced.... However, despite these improvements, little progress has been made on the much more politically divisive issues of N inputs from agricultural activity and car emissions, overfishing, and coastal habitat loss. Until these much more difficult issues are confronted, the biogeochemical cycles of the coastal zone will remain under threat.'*

This citation by Jickells (1998) clearly stresses the priority topics that have to be tackled in order to promote conditions that are required for the sustainable development of our coastal living environment:

The first three issues cited by Jickells (1998) are illustrated in the present document with showcases selected from the ELOISE projects. These studies respectively address 1.-the assessment of atmospheric deposition, 2.-the modelling of nutrient transport through watersheds, 3.-an assessment of the effects of overfishing on the coastal food-web.

# 1 Towards a consistent assessment of atmospheric deposition in coastal regions

## 1.1 THE ISSUE

Smog, acid rains and depletion in the troposphere ozone layer have incited managers to tackle these issues with measures leading to a reduction of the atmospheric emissions. Since 1974 most environmental legislation referring to atmospheric deposition is governed by international agreements:

In June 1999 the European Commission presented a proposal for a directive setting national emission ceilings (NECs) for four air pollutants that cause acidification and the formation of ground-level ozone: sulphur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), volatile organic compounds (VOCs), and ammonia (NH<sub>3</sub>). After two years of negotiation, it was adopted by the Council of Ministers and the European Parliament in July 2001.

The aim of the directive is to gradually improve, through a stepwise reduction of the four pollutants, the protection of both human health and the environment throughout the EU. By means of EU strategies to combat acidification and ground-level ozone, the directive establishes interim environmental quality targets that are to be attained by 2010.

These targets constitute the first step towards the achievement of the long-term objectives of not exceeding the so-called critical loads, and of effective protection of human health against risks from air pollution, as laid down in the Fifth Environmental Action Programme. This NEC directive is the key legislation for the achievement of those environmental objectives, as well as for attaining the EU air quality standards for a number of pollutants, including SO<sub>2</sub>, NO<sub>2</sub>, fine particles (PM<sub>10</sub>), and ozone.

The effects of atmospheric emissions are furthermore not restricted to smog and acid rains, and it is now recognized as an important input of nutrients to the coastal area. As an example, for the North Sea that is surrounded with industrial sources of atmospheric emissions, the atmospheric contribution to the total land based nitrogen input has been reported to be on the order of 30% for the total North Sea (North-Sea-Task-Force 1993).

Although delivered as a diffuse flux in contrast to localized river inputs (Jickells 1998), the atmospheric nutrient input can be locally distributed and episodic (de Leeuw et al. 2003a). As a consequence, the assessment of the effects of atmospheric deposition on the coastal

ecosystem requires a monitoring with a high resolution matching the spatio-temporal distribution of these events.

Our ability to recognize to which extent individual emission's sanitation contribute to an abatement of the nutrient deposition on sea require the assessment of the relevant processes acting on the trajectories and transformations of the aerosols between their emission and their deposition in the coastal area.

## 1.2 WHAT IT TAKES

This was one of the main objectives of the ANICE project to improve transport-chemistry models that estimate nitrogen deposition to the sea. Of particular emphasis within ANICE is the influence of coastal zone processes. Both short lived extreme events and chronic nitrogen input are considered in the project.

ANICE focuses on quantifying the deposition of atmospheric inputs of nitrogen compounds ( $\text{HNO}_3$ ,  $\text{NO}_3^-$ ,  $\text{NH}_3$  and  $\text{NH}_4^+$ ) into the sea, both near the coast and in open water, and the governing processes.

Experimental and modelling work was conducted to investigate the processes involved in the chemical transformation, transport and deposition of atmospheric nitrogen compounds. Long-term observational programme using scientific equipment mounted on commercial ferries, complemented by two intensive field experiments that focus on process studies.

Intensive campaigns were designed to study relevant processes to the coastal system and that should be included in the models whereas long-term monitoring from ferries, provided data from the open North Sea.

The dual scale in the observations was paralleled with the use of two atmospheric chemistry transport models: ACDEP for the calculation of atmospheric inputs of nitrogen to the whole North Sea, integrated over periods varying from 6 h to a year; METRAS to calculate the atmospheric nitrogen input to coastal waters with a high resolution in space (down to 100 m) and time (to minutes).

## 1.3 WHAT YOU GET

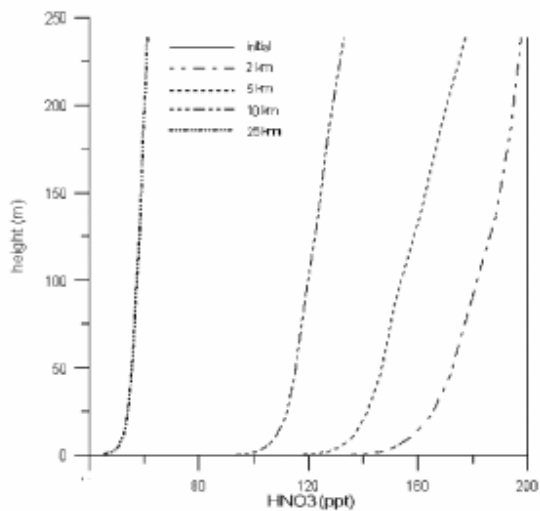
### 1.3.1 Variations at small spatial and temporary scales

Results presented in Figure 1a show the variations in both the  $\text{HNO}_3$  concentrations and their spatial gradients with fetch (de Leeuw et al. 2001). The high sea spray concentrations over the surf zone cause an immediate effect when the air mass passes the coast line. The uptake by sea spray aerosols is most evident at lower altitude where the concentrations of the particles are highest. Diffusion distributes the particles homogeneously in the vertical, causing a homogeneous uptake in the whole column. At a fetch of 25km the profile becomes almost uniform except very close to the surface.

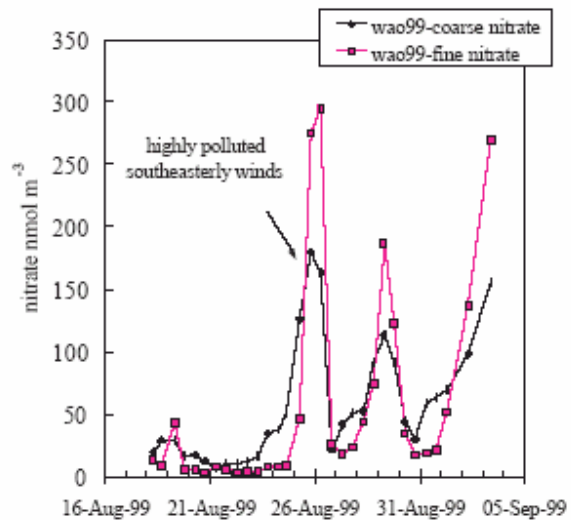
Figure 1

a.- Modelled concentration profiles of nitric acid for various distances from the coast (de Leeuw et al. 2001). b.- Temporal variation of the concentrations of nitrate and ammonium in the fine and coarse fractions measured at Weybourne during the ANICE experiments in August/September 1999 (de Leeuw et al. 2003b).

a



b



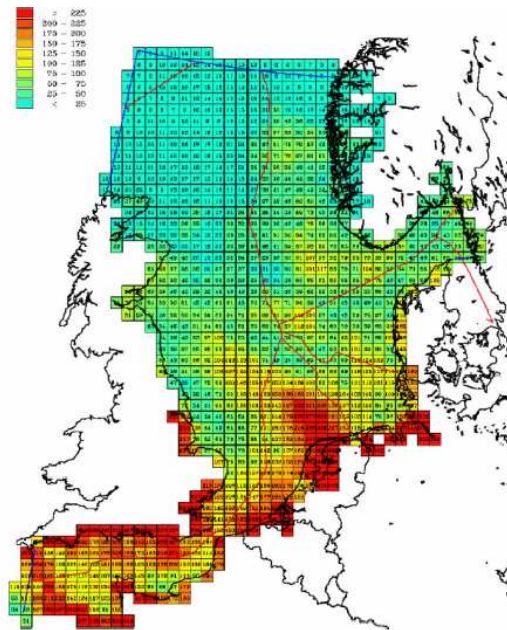
Large deposition of nitrogen may occur during short periods (de Leeuw et al. 2003). This is illustrated with an example for the ANICE experiment in August 1999, when the southern North Sea experienced a short period of strong south-easterly flow. Mass concentrations of ammonium and nitrate aerosol in the fine and coarse fractions measured at WAO during this period are presented in Figure 3. During the period centred on 26 August 1999, the atmosphere provided enough nitrogen to fix  $5.3 \text{ mmolC m}^{-2} \text{ day}^{-1}$ .

### 1.3.2 Total nitrogen deposition to the North Sea

Figure 2 shows the spatial distribution of nitrogen deposition to the North Sea and the strong gradients near the source areas that result from the processes described above. They have the effect of focusing atmospheric deposition into coastal areas already stressed by various other anthropogenic inputs (Jickells, 1998).

**Figure 2**

Total atmospheric nitrogen deposition to the North Sea in August 1999. Deposition values are given in  $\text{kgNkm}^{-2}$  (de Leeuw et al. 2003b)



In large-scale atmospheric transport models such coastal chemical processes are generally not included. Without these, it is not possible to effectively manage nitrogen enrichment issues in coastal waters.

### **1.3.3 Potential effects on primary production**

In the Kattegat Strait, the events of high atmospheric wet deposition could increase the growth of chlorophyll around 20% or more (Hasager et al. 2003). Similarly, results by Spokes et al. (2000) suggest that about 30% of the new production in eastern Atlantic surface waters off Ireland can be supported by atmospheric inputs in May 1997 and that most of the input occurs during short lived, high-concentration, south-easterly transport events.

The episodic fluxes largely determine the total primary productivity due to atmospheric N-deposition in the area. For the southern North Sea, the atmospheric contribution is estimated at ca 5.5% of the total required new nitrogen. For the entire North Sea the atmospheric contribution is ca 3.2%. Although these numbers may not seem impressive, presented results show that most of the nitrogen is delivered during short episodes. One such episode resulted in an average deposition of  $0.8 \text{ mmolN m}^{-2} \text{ day}^{-1}$  (de Leeuw et al. 2003b) which has the potential to promote primary productivity of  $5.3 \text{ mmolC m}^{-2} \text{ day}^{-1}$ .

## 1.4 PERSPECTIVES

- ➔ An interesting feature of the ANICE project is the use of the two complementary atmospheric chemistry transport models, ACDEP and METRAS. This combined modelling effort is expected to lead to a major improvement in the estimate of atmospheric inputs into the North Sea, which can subsequently be used in effect studies.
- ➔ Most current models use grids that are too coarse to describe the governing processes with sufficient accuracy, particularly in coastal regions as demonstrated with the ANICE studies (de Leeuw et al. 2001).
- ➔ The high dynamics in atmospheric deposition on both spatial and temporal scales and the importance of wet deposition stress the need for a coupling of the deposition and meteorological models.
- ➔ The generalisation for Europe-wide applications will require from the models to become more generic. For example, when focus is on nitrogen deposition in the Atlantic zone, a lot of effort is put on the assessment of the P-deposition in the Mediterranean Sea. In the Mediterranean where abundant cyanophyceae are actively fixing the atmospheric Nitrogen, N is indeed not considered as a limiting factor (Migon et al. 2001, Markaki et al. 2003).

## **2 Chasing after nutrients through watersheds**

### **2.1 THE ISSUE**

The European coastal zones are areas of great concern because of growing problems associated with increasing inputs of nutrients since the late 1960s. These have resulted in a higher incidence of harmful algal blooms and other eutrophication phenomena and caused deleterious impacts on fisheries and tourism (Lancelot et al. 1989).

Since the late 1980s agreements have been made at national and international levels to substantially reduce the levels of nutrient emissions to the aquatic environments. The last directives from the European Commission have defined a strategy where every effort to combat eutrophication in the maritime area is requested, in order to achieve, by the year 2010, a healthy marine environment where eutrophication does not occur.

After ca 20 years of sanitation measured, dramatic changes in the discharge of phosphorus to the North-Sea have been observed, whereas nitrogen emissions did not change much over the same period (de Jonge et al. 2002).

The implementation of these measures represents a high cost for the community (Conley et al. 2002) and this demands an efficient assessment of their effects on the environment with respect to their objectives. Indeed critical levels for nutrient supply may vary from one system to another and uniform policy for nutrient sanitation may be either too restrictive or too permissive with respect to their objectives (avoidance of undesirable disturbance).

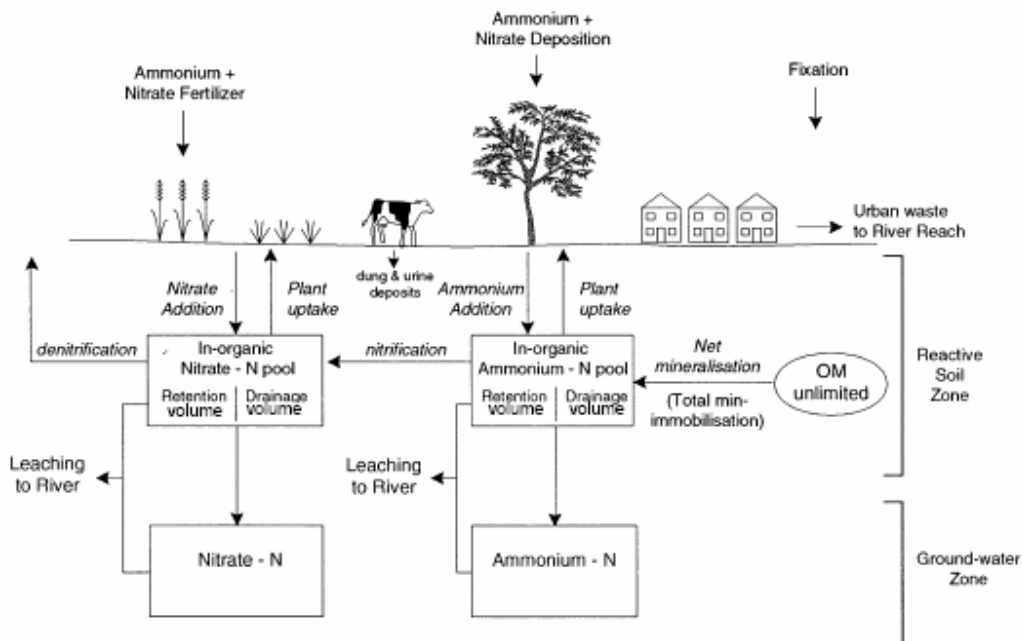
## 2.2 WHAT IT TAKES

The ELOISE projects INCA, EROS2000/EROS21, RANR have focused on the modelling of nutrient transformation processes in the watershed and the river network. The main aim was to relate statistics of land use and human (agricultural, domestic) practices of nutrient input into the system, to the load of rivers.

**INCA** is a deterministic model that includes land and river processes, and is driven by spatially explicit input data (Figure 3). The model accounts for stocks of ammonium and nitrate in the soil and ground water pools, and in the stream reaches. The model also simulates the flow of water through the plant/soil system from different land use types to deliver the N load to the river system, which is then routed downstream after accounting for direct effluent discharges, and in-stream nitrification and de-nitrification.

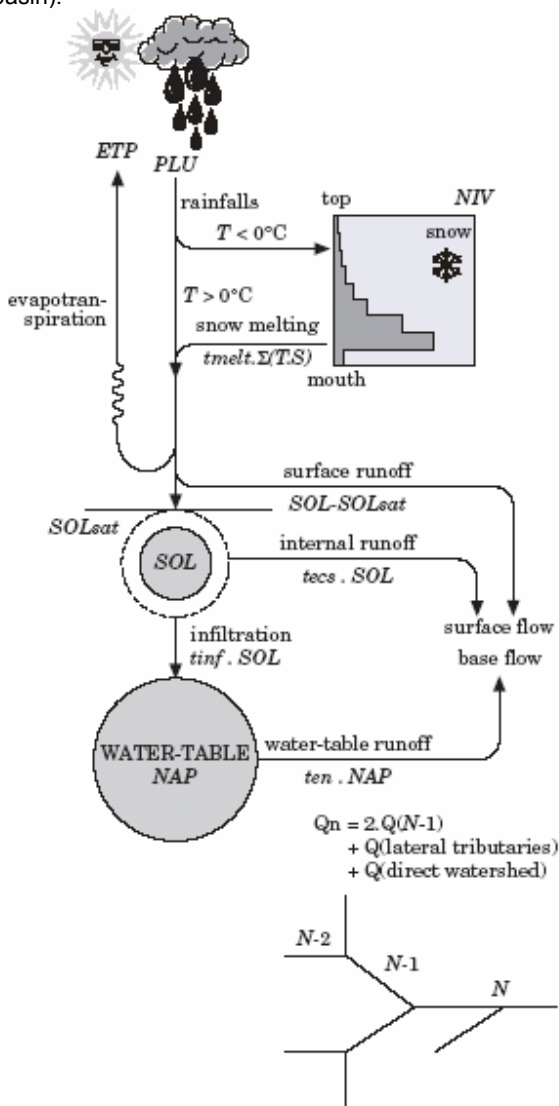
**Figure 3**

The structure of the land component of INCA clearly showing all the individual processes taken into consideration in this full-deterministic model.



The **RIVERSTRAHLER** model (Billen & Garnier 2000, Garnier et al. 2002), first applied to the Seine (Billen et al. 2001), was used to describe nutrient and ecological dynamics in the Danube watershed and river.

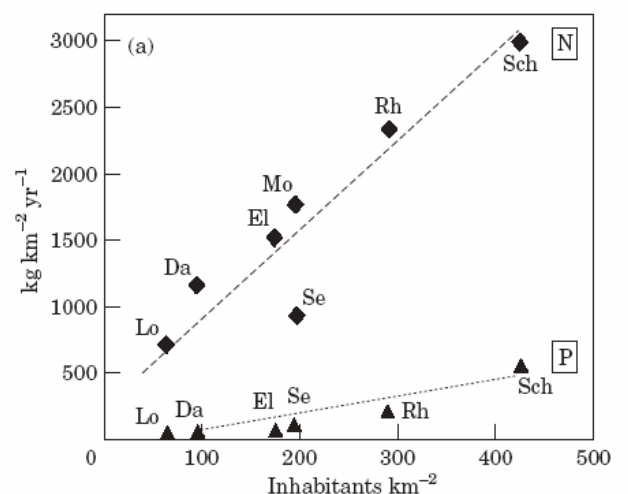
**Figure 4**  
Schematic representation of the HYDROSTRAHLER model and its parameters. *NAP0*: initial level of the water-table (mm); *SOLsat*: water saturation level of the soil (mm); *tinf*: rate of infiltration (decade<sup>-1</sup> 1); *tecs*: rate of superficial runoff (decade<sup>-1</sup> 1); *ten*: Water-table runoff (decade<sup>-1</sup> 1); *tmelt*: degree-decade factor (mm<sup>-1</sup> C<sup>-1</sup> 1 decade<sup>-1</sup> 1); *NIV0*: initial snow depth (mm at the top of the basin).



This model synthesises the hydrological network of a river basin by stream order (HYDROSTRAHLER module), which reduces the computational load to a reasonable level.

The river model for the different stream orders of several sub-basins integrates full ecological dynamics, including transformations of nutrients in the ecosystem (biogeochemical RIVE module). For the different sub-basins, nutrient and organic inputs are derived from gross statistics (population density, type and intensity of industrial activity, fertiliser application, land use) (Figure 5).

**Figure 5**  
Relationship between specific fluxes of nitrogen and phosphorus (kgN or P km<sup>-2</sup>) and population density (inhabitants km<sup>-2</sup>). Da: Danube River; El: Elbe River; Lo: Loire River; Mo: Mosel River; Rh: Rhine River; Sch: Scheldt River; Se: Seine River. From Garnier et al. (2002).



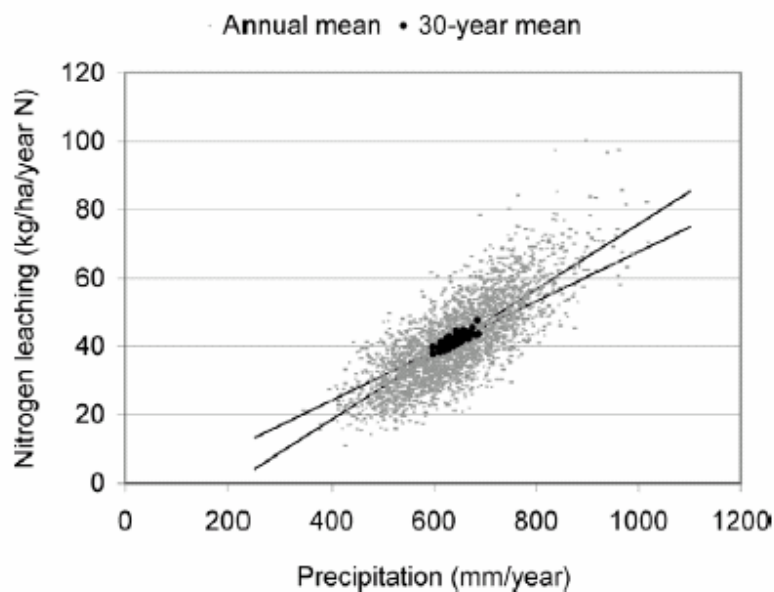
**Aggregating chaos in rules.** Models require input data in quantities that grow exponentially with the model complexity and a recurrent problem confronting model-users is the lack of data at the desired spatio-temporal resolution.

Forsman & Grimvall (2003) examined for the RANR project under what circumstances spatially distributed inputs to a substance transport model can be replaced by spatially aggregated inputs without jeopardising the accuracy of spatially aggregated model outputs. The SOIL/SOILN model was used by Forsman & Grimvall (2003) as test case according to the following rationale:

- 1.-Response of model estimates for leaching of nitrogen from the root zone to variation in meteorological inputs, soil and crop type, and fertiliser application.
- 2.-Suppression of non linear features by i.- aggregating model outputs over one or several years, and (ii) considering relationships between different components of a multivariate model output (Figure 6).

**Figure 6**

Regression lines fitted to annual and 30-yr means of precipitation and nitrate leaching. Soil parameters and agricultural practices were selected to correspond to cultivation of barley on loamy sand in southern Sweden



Finally, Forsman & Grimvall (2003) presented a simplified model of the expected total leaching of nitrogen from the root zone in agricultural areas.

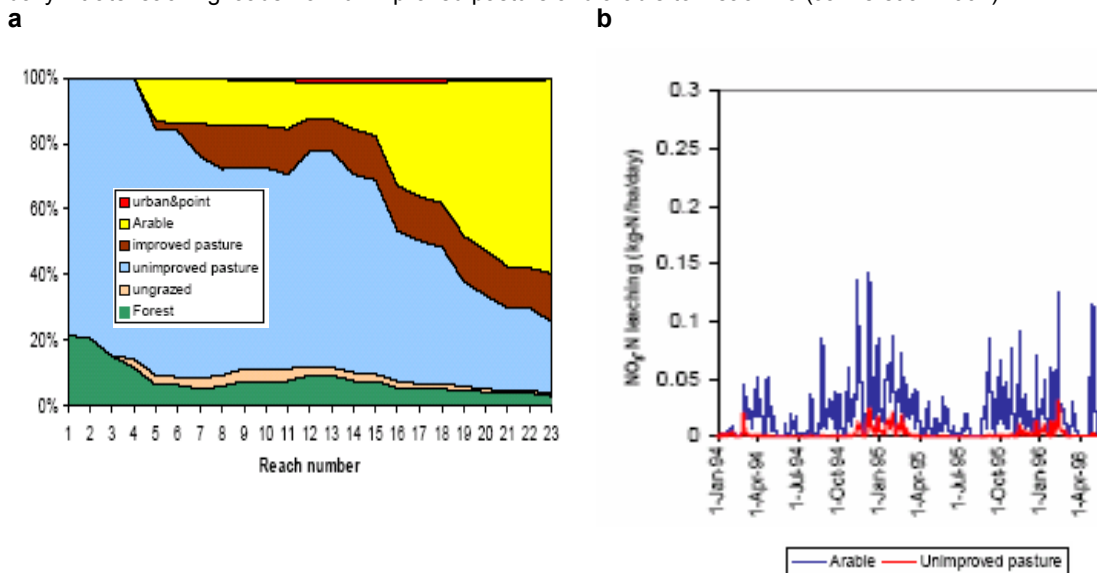
## 2.3 WHAT YOU GET

### 2.3.1 Modelling nitrogen dynamics and distributions in the River Tweed

INCA-scenarios on the possible impacts of environmental change on nitrate concentrations on the Tweed were examined by Jarvie et al. (2002). These include the effects of (i) implementing different recommendations for fertiliser use and land use change under the Nitrate Sensitive Areas (NSA) Scheme and the Scottish Code of Good Agricultural Practice, (ii) worst case scenario changes linked to a dramatic reduction in livestock numbers as a result of a crisis in UK livestock farming and (iii) changes in atmospheric nitrogen deposition.

Figure 7

a.-Simulated relative contributions of different sources to the nitrate load along the River Tweed during 1995. b.- Simulated daily nitrate leaching loads from unimproved pasture and arable to Reach 13 (Jarvie et al. 2002).



The explicit definition of the nitrogen sources in the formulation of the INCA model, allows to trace their contribution to the river nitrogen pool throughout the stream (Figure 7-a). According to the level of detail in the input variables, INCA may produce highly detailed predictions on the nutrient discharges throughout the year at any point in the river stream (Figure 7-b). The simulations demonstrated the importance of leaching from arable land to the loads of nitrate draining from the Tweed catchment (up to approximately 70% of monthly nitrate loads in 1995).

The INCA Tweed-model was used to make predictions on scenario's relevant to management by changing the relevant input parameters (Jarvie et al. 2002):

- ✓ -a 20% reduction in fertiliser inputs is predicted to result in average reductions of 12% in-stream nitrate concentration
- ✓ -by allowing all arable land to revert to its semi-natural state (ungrazed, unfertilized grassland), INCA predicts an average nitrate reduction at Norham of 57%.
- ✓ -by allowing all grazing land to revert to its semi-natural state (ungrazed, unfertilised grassland), INCA predicts an average reduction in nitrate concentrations of 20%.

### 2.3.2 Effect of land use and management on nutrient fluxes in the Danube

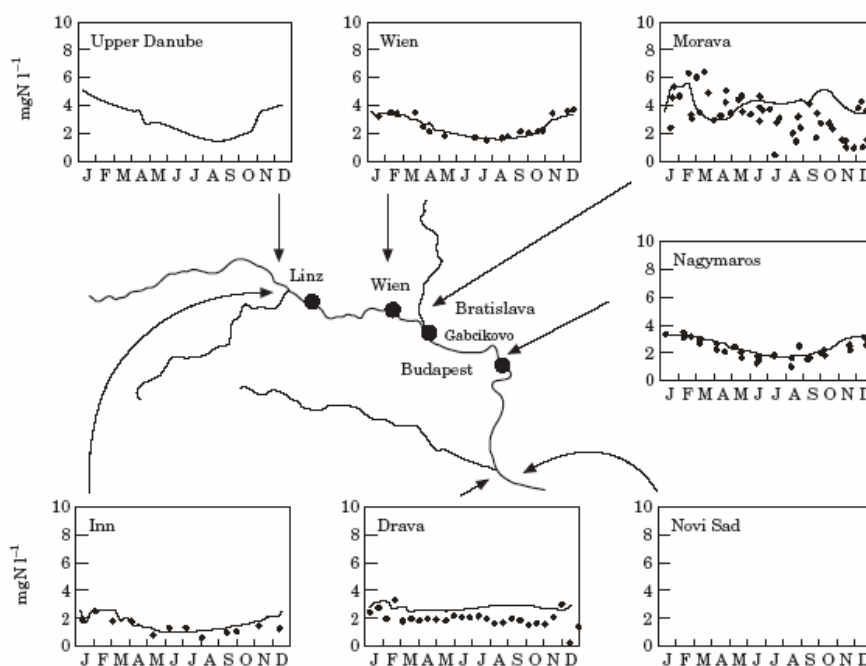
The aim of the modelling approach developed for the Danube River, is to establish how land use and management of the whole watershed are linked to nutrient (N, P, Si) delivery and retention by the river (Billen & Garnier 2000, Garnier et al. 2002).

The model was validated for the period from 1988 to 1991 on the basis of available observations of the major water-quality variables involved in the eutrophication processes (inorganic nutrients, phytoplankton biomass, dissolved oxygen, etc.).

A reasonable agreement was found between the simulations of the model and the observations (Figure 8). Nutrient fluxes to the Black Sea, calculated for our reference period, are in the same range as those obtained via other approaches.

**Figure 8**

Upper and (b) lower course of the Danube River. Simulation by the RIVERSTRAHLER model of the seasonal nitrate variations for the period 1988–1990. Experimental data for the same period are given for comparison.



Since the beginning of the 1990s, a drop in the annual N and P delivery of the Danube to the Black Sea has been observed. This drop is concomitant with the sharp decline in industrial activity between 1989 and 1994 and was paralleled with signs of recovery of the Black Sea coastal ecosystem (references in (Garnier et al. 2002)).

In order to verify whether the trends observed in the Danube nutrient delivery can indeed be explained by the documented modification of human activity in the watershed, a scenario was constructed by Garnier et al. (2002) to reproduce these new constraints:

- ✓ Reduction of industrial released nutrients by 30%, 40% and 50% in the Hungarian, Slovakian and Romanian sub-basins respectively.
- ✓ Reduction in the release of phosphate due to the decreased use of P-containing detergents following the economic recession in most former Eastern Bloc countries and deliberate policy as in Austria.
- ✓ Decrease in diffuse nitrogen sources due to the declining use of fertilizers, concomitant with economic recession by 20% in Hungary and Slovakia, and 40% reduction in Romania.

With outputs to the Black Sea estimated by 644 kt ( $\text{NO}_3\text{-NH}_4$ )  $\text{yr}^{-1}$  and 15 kt  $\text{PO}_4$   $\text{yr}^{-1}$ , the model predictions were very close to the observed discharges as 530 and 12 respectively. This allowed confirming that the observed trends for the discharges were to be ascribed to the decline in the economic activity in the Danube catchments.

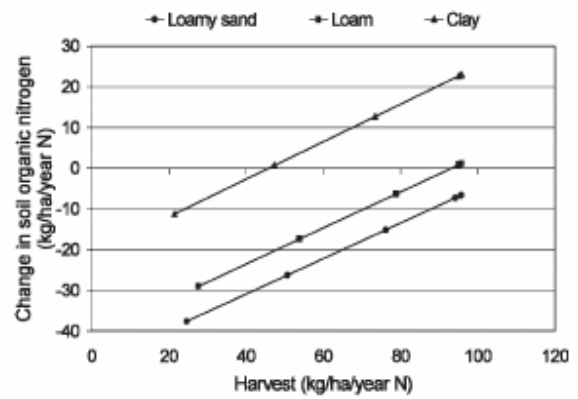
### 2.3.3 Land use effect on nitrogen retention leaching from agricultural soils

**Table 1**  
Levels of input variables used in the simulation study by Forsman & Grimvall (2003).

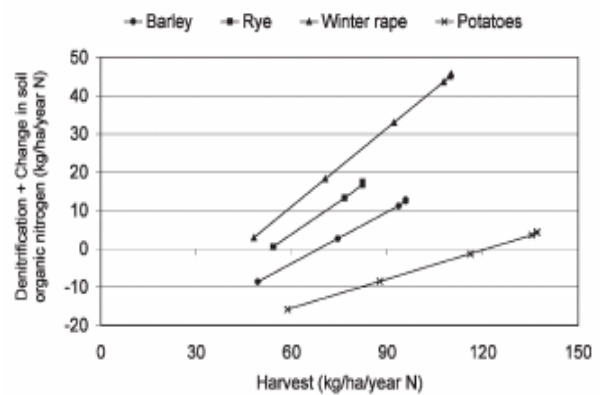
Mineral fertilisers (kg ha <sup>-1</sup> yr <sup>-1</sup> N)	Manure (kg ha <sup>-1</sup> yr <sup>-1</sup> N)	Atmospheric deposition (kg ha <sup>-1</sup> yr <sup>-1</sup> N)	Crop	Soil
0	0	20	Barley	Loamy sand
40	50		Spring wheat	Loam
80	100		Spring rape	Clay
120	150		Potatoes	
160	200		Winter wheat	
200	250		Rye	
240			Winter rape	
			Sugar beets	
			Ley	

The reduced version of the SOIL/SOILN model as constructed by Forsman & Grimvall (2003) was used to make predictions on nitrogen retention/leaching from agricultural soils under different land use practices (Table 1). Two examples from these predictions are given below:

For a given crop and varying levels of mineral fertiliser, the change in storage can be expressed as a linear function of nitrogen removal through harvesting, and the lines representing different soils have the same slope



For a given crop (and soil), the denitrification along with mean annual change in the pool of organic nitrogen in the soil is also almost a linear function of the amount of nitrogen removed through harvesting (although denitrification involves several non-linear processes). However, the slopes of the lines are dissimilar, thus this linear relationship cannot be extended to encompass different crops without introducing interaction effects as well.



Such simplified models are useful for extrapolating models from small to large spatial units. Moreover, the low computational cost of reduced models is an obvious advantage when the objective is to incorporate models of complex systems into interactive decision support tools that demand short response times.

## 2.4 PERSPECTIVES

- ➔ The INCA approach has been very good in producing a user friendly and widely available piece of software dealing with N impacts in catchments. The bringing together of field workers, hydrobiogeochemists and modellers has been a good and challenging one with "cross peer reviewing" (Colin Neal, pers. comm.).
- ➔ While seasonal trends in nitrate concentrations was well represented by INCA simulations, extremely high flows and associated intermittent high nitrate concentrations were often poorly simulated. This problem is likely to remain for a deterministic model as INCA.
- ➔ The impacts of the nutrients on the aquatic environment are linked to biological functioning in a connected fashion and there is a major need for an integrated (N,P,Si)-INCA model to examine their relative importance and potential nutrient limitation.
- ➔ The absence of biological processes within the river stream as in the INCA model makes it difficult to apply in case of slow-flowing lowland eutrophic rivers where the role played by plant uptake may become significant.
- ➔ The RIVERSTRAHLER model is one of the few available tools for modelling nutrient cycling and ecological functioning of entire drainage networks as a function of the properties of their watershed.
- ➔ The successful RIVERSTRAHLER application to the Seine (Billen & Garnier 2000, Billen et al. 2001) has proven the suitability of this modelling approach for management issues. The
- ➔ Danube-RIVERSTRAHLER application requires additional input data for further validation of the model.
- ➔ The pragmatic approach used in the RANR project highlights potential solutions for areas where input data are scarcely distributed.
- ➔ Most of the models investigated here have been developed for temperate climate zones and may not be directly suitable for extremely dry climates.

### **3 Alteration of coastal food webs by human activities**

#### **3.1 THE ISSUE**

The effects of mankind activities on the coastal areas are mostly negative and often destructive. So far land-based emissions (via river or atmosphere) of industrial, agricultural or domestic effluents are concerned; mitigation measures are rather simple in conception since it mostly consists in sanitation procedures.

When fishery activities are suspected to negatively alter the ecosystem, the mitigation procedures are more complex to define as to know the level of reduction required to reach sustainability. In a long time perspective, the fishing fleet must be managed, so that its capacity matches the production of fish. One aspect of this is to keep the fishing mortality at a sustainable level, i.e. that today's fishing capacity/intensity must not be so high that it will reduce the spawning stock biomass to such an extent that it would force to reduce or ban fishing in the future.

Beside the risk of stock collapse, fishing activities may have destabilizing effects on ecosystems by changing the biomass of specific components from the food web. These effects will depend on the nature and size of the catch and on its relation with the rest of the ecosystem.

As a consequence a consistent assessment of the sustainable levels for fishing pressure will require knowledge (and prediction capacity) on the food web functioning.

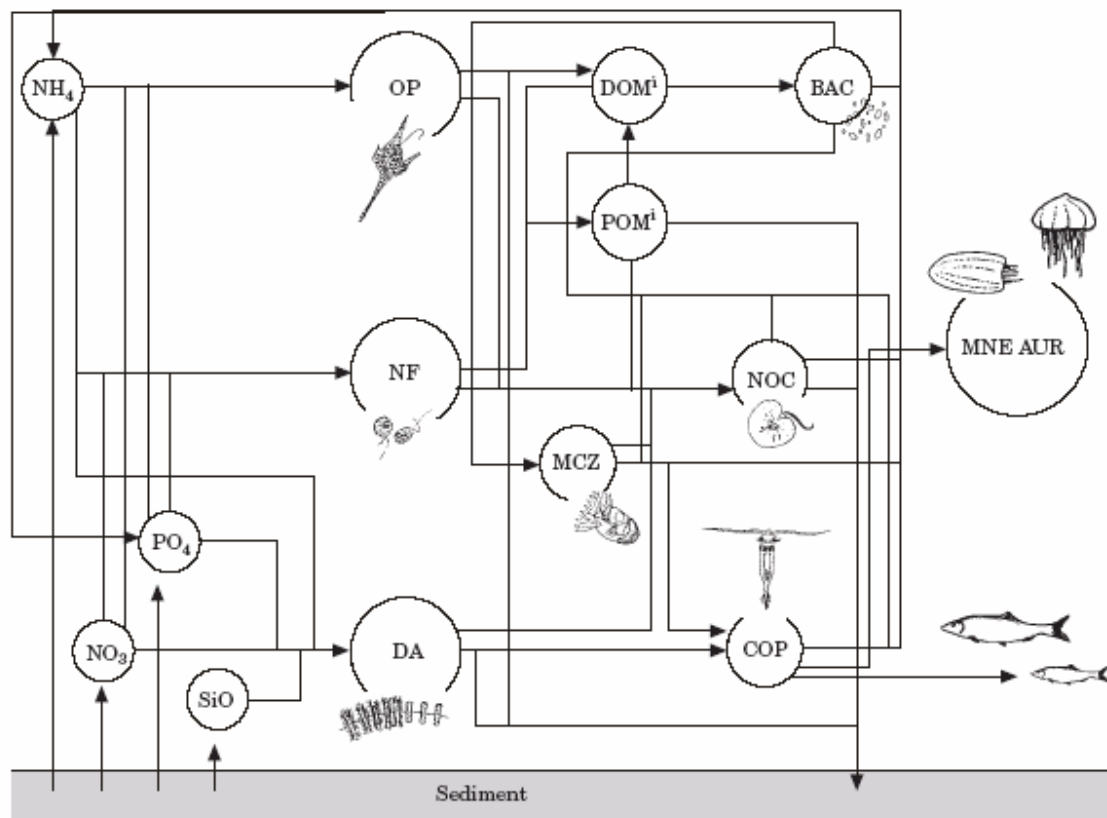
### 3.2 WHAT IT TAKES

This was the aim of the EROS-21 project to develop a coupled ecological model that explicitly describe the bottom-up and top-down controls of the pelagic food chain for an adequate representation of the fate of the nutrients brought into the water column.

BIOGEN, a high trophic-resolution ecological model was applied by Lancelot et al. (2002) to the Black Sea system (Figure 9). This model originally developed to track the impacts of altered nutrient discharges was also shown to produce consistent predictions on the effect of fishing intensity on the ecosystem structure.

**Figure 9**

Diagrammatic representation of the structure of the BIOGEN model. Inorganic nutrients include ammonium (NH<sub>4</sub>), nitrate (NO<sub>3</sub>), phosphate (PO<sub>4</sub>) and silicic acid (SiO). Organic matter is composed of dissolved (DOM<sup>1,2</sup>) and particulate (POM<sup>1,2</sup>) matter each with two different biodegradability classes. Phytoplankton is composed of three groups: diatoms (DA), autotrophic nanoflagellates (NF) and opportunists (OP). Bacterioplankton is represented by BAC. Zooplankton includes microzooplankton (MCZ) and copepods (COP). The gelatinous food-chain is composed of Noctiluca (NOC), Aurelia (AUR) and Mnemiopsis (MNE). From (Lancelot et al. 2002).



BIOGEN, describes the carbon, nitrogen, phosphorus and silicon cycling throughout aggregated chemical and biological compartments of the planktonic and benthic marine systems, in the north-western Black Sea.

Particular attention was paid to establishing the link between quantitative and qualitative changes in nutrients, phytoplankton composition and food-web structures. The BIOGEN numerical code structure includes 34 state variables assembled in five interactive modules describing the dynamics of:

(1) phytoplankton, three groups diatoms, nanophytoflagellates, non-silicified opportunistic species.

(2) meso- and microzooplankton with high food selectivity.

(3) gelatinous organisms (omnivorous Noctiluca, carnivores Aurelia and Mnemiopsis) as trophic dead-end.

(4) planktonic and (5) benthic bacteria both responsible for organic matter degradation and associated nutrient regeneration processes.

Lancelot et al. (2002) present the first steps preliminary to the implementation of the 3-D BIOGEN:

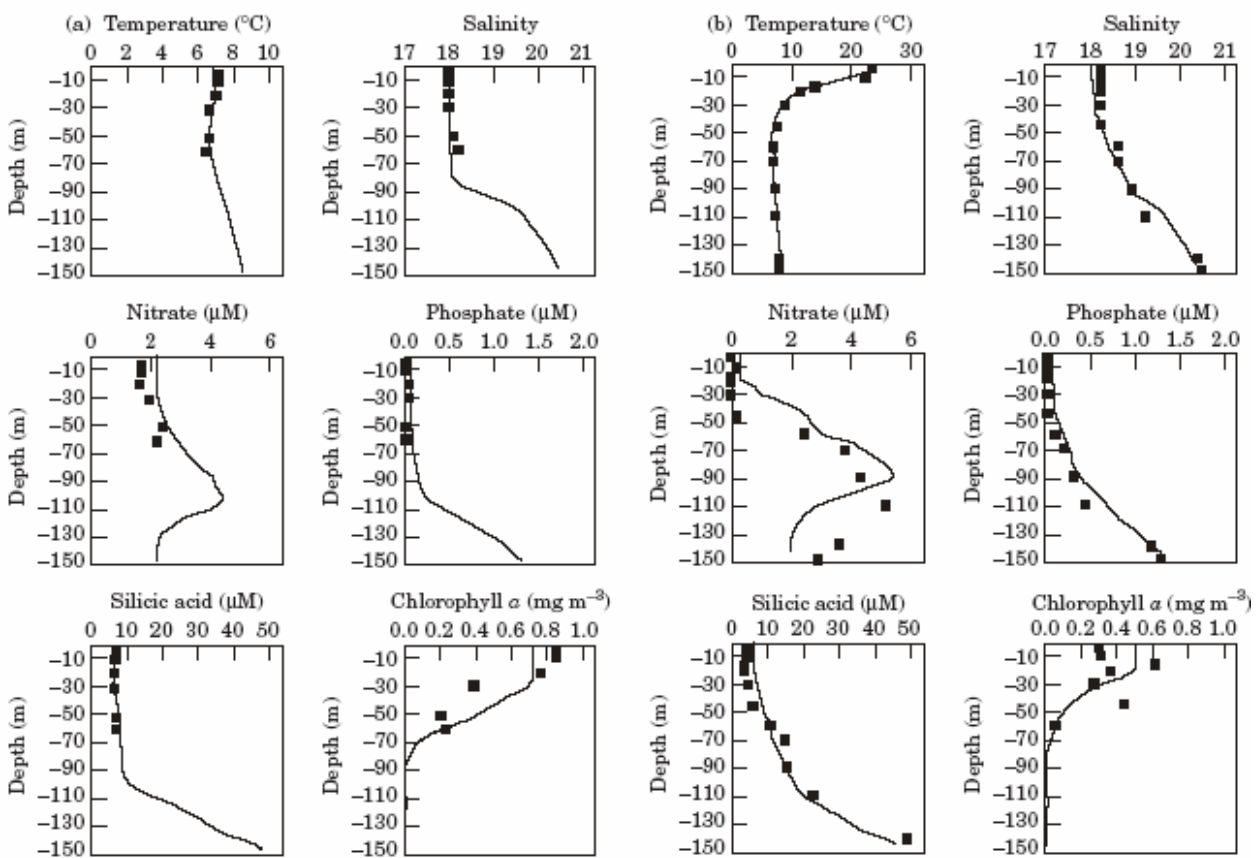
1.- BIOGEN model coupled with a 1-D vertically resolved physical model

2.- BIOGEN model implemented as a two-box model resulting from the coupling between the 1-D vertically resolved open-area model and a volume-variable 0-D box model of the coastal area submitted to Danube inputs.

### 3.3 WHAT YOU GET

The capability of the BIOGEN model to simulate the Black Sea ecosystem functioning was demonstrated by running the model for the period 1985–1995. Reasonable agreement was observed between model predictions and data available for the central basin, both seasonally and in magnitude. As an example, vertical profiles of BIOGEN simulations and nutrients and chlorophyll a observations compared rather well for spring and summer periods (Figure 10).

**Figure 10**  
1-D BIOGEN simulations in the open Black Sea water column. Observations recorded in (a) April 1997 and (b) July 1995. data (squares), model (line).



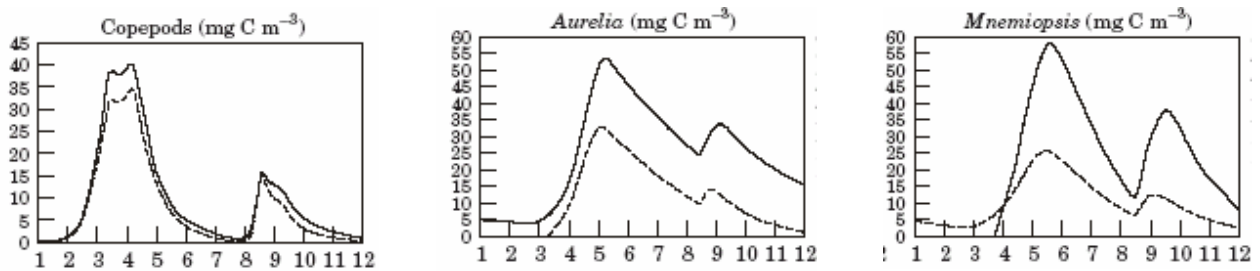
The BIOGEN model has further been used by Lancelot et al. (2002) to test the recent hypothesis of Gucu (2002) on the crucial role of overfishing rather than man-made eutrophication as being responsible for the successful development of gelatinous carnivores in the north-western Black Sea in the late 1980s–early 1990s.

The influence of the fisheries industry on the blooming of gelatinous carnivores was tested by running BIOGEN with the Danube nutrient loads of 1991 and changing the fishing coefficient.

The latter was indirectly considered by modifying the mortality coefficient of copepods, where a lower value corresponds to a higher fish pressure.

**Figure 11**

Sensitivity of the 1991 BIOGEN predictions to fishing pressure obtained indirectly by changing copepod mortality to fish predation. (---), current 1991 prediction; (—), twofold decrease of copepod mortality by fish pressure (Lancelot et al. 2002).



Model simulations (Figure 11) suggest, under conditions of well-balanced nutrient enrichment, a positive link between fishing pressure and gelatinous carnivores. A greater than two-fold increase of the biomass of both carnivorous gelatinous organisms is predicted for a doubling of fishing pressure.

This example clearly evidences the kinds of dramatic shifts that may result from man-made activity in a coastal ecosystems. Predictions on such features require the use of models that explicitly include the relevant ecological groups and processes.

### **3.4 PERSPECTIVES**

- This example demonstrates the capability of mechanistic models to handle the complex and nonlinear nature of the link between human activities and the functioning of a coastal ecosystem.
- Ideally the BIOGEN model should be integrated in a 3-D frame of high spatio-temporal resolution. The complexity of the BIOGEN model makes however its direct coupling with the required 3-D physical model yet technically unworkable.

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